BIO-OPTICAL CHARACTERISTIC OF CASE-2 COASTAL WATER SUBSTANCES IN INDONESIA COAST

I KETUT SWARDIKA

Abstract

The results of our study in the bio-optical characteristic of mixed water substances or referred as water leaving radiance of chlorophyll-a in case-2 water. Apparent optical properties of chlorophyll-a (Chl-a) influence by others water constituents eq. particle backscattering. and yellow substances absorption coefficients. We studied varies Chl-a concentration from 0.001 ug/l -65.0 ug/l. mixed by suspended particle (SS) concentration from 0.01 mg/I ~ 50.0 mg/1, and yellow substances absorption coefficients (ay) from 0.001 m" - 5.0 m" . We used the simple radiative transfer equation in seawater method to simulate the Normalized water leaving radiance (NLw) of Chl-a. NLw of Chl-a with concentration less than 1 ug/l and less influence from other substances similar to NLw of pure sea water characteristic. This high reflected at blue band. Otherwise. Chl-a concentrations more than I ug/l, are similar to the absorption characteristic of Chl-a with fluorescence peak at 680 nm. The Cross characteristic (Hinge point) occurs at 530 nm. Higher SS concentration causes NLw characteristic of Chl-a change, where hinge point moves toward the longer wavelength. Higher yellow substance absorption coefficients cause NLw characteristic of Chl-a has strange behavior. To keep the NLw Chl-a characteristic, SS concentration should be no more than 1 mg/L and ay coefficient no more than 0.01 m .

Keywords: bio-optical, chlorophyll, the Normalized water leaving radiance

I. Introduction

Indonesian seas are located surrounding many islands with beautiful beach and marine culture. Coastal area is the most utilization area in this country. The Badung strait at the Bali Island and the Saleh strait at the Sumbawa Island arc representatives of the coastal territorial water condition nowadays. The first location is the representative of the tourist activity areas and the second location is the representative of the marine culture industry. Water quality of seawater becomes the important problem in die next decade, and can be monitored by remote sensing.

Radiative transfer in seawater is determined by the inherent optical properties to dissolved organic substances and paniculate material, including both algal and non-algal components. It is well recognized, however, that in most marine areas, phytoplankton contributes to a greater extent than non-biogenic material to the optical status of seawater (Morel, 1988). Therefore, the optical properties of phytoplankton play a key role in the models of light transmission under water. In addition, absorption of light is an important function of phytoplankton cells that drives photoautotrophic production in the ocean. For this reason, the analytical models of phytoplankton growth and photosynthesis rely on the in vivo absorption coefficient of phytoplankton.

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This inherent optical property is also the major factor determining the reflectance signal from seawater, whose spectral variations are used in remote sensing to estimate oceanic biomass (Gordon and Morel, 1983). Methods have also been developed to compute primary production from the satellite imagery, which also rely heavily on the optical properties of phytoplankton (Piatt and Sathyendranath, 1988). Direct measurements of in vivo light absorption by phytoplankton are difficult, considering the low concentration of algal cells in nature (when compared to cultures) and the distribution of photons between phytoplankton and other particulate material such as detritus and sediment. Recently, however, the methods have been developed to measure the absorption spectra of live phytoplankton from natural seawater samples (Kishino *et ah,* 1985). Applications of these methods to field samples are still sparse, particularly in the coastal waters.

The satellite sensor monitors the ocean color by measuring the water leaving radiance at a limited number of wavebands in the visible domain, and then uses the signal to infer the concentrations of waters constituents such chlorophyll-a, in the near-surface layers of the ocean. The mixed water constituents in the ocean near the coast might modify the signal from phytoplankton pigment. The purpose of this study is to evaluate the bio-optical characteristic of phytoplankton in the ocean color and understand the effect of other substances.

II. Material and Methods

a. Mixed of Water Substances

It is recognized that the optical properties of natural water are influenced by several substances. From a practical and optical perspective, we can recognize three main components, in addition to pure water: the first is phytoplankton. This component is taken to include phytoplankton and other microscopic organisms. Actually, we call this the "phytoplankton" component, in recognition of their major influence on optical properties. The second is Inorganic Suspended material. Even though the microscopic organisms are also "suspended" material, we use this term here to represent only the inorganic suspended material. The third is Yellow substances. These are colored, dissolved, organic substances. We also include the "detrital" particulate material, which generally has the absorption characteristics similar to the yellow substances. These components are making complex water type, from an optical point of view.

We can use the concentration range at Phytoplankton from 0.001 ug/1 until 65.0 ug/1, we practically observe apparent optical properties of chlorophyll-a including the suspended material and the yellow substances. The concentration range of suspended material is from 0.01 mg/1 until 50.0 mg/1, and the absorption coefficients (ay) of yellow substances is from 0.001 m$^{''1}$ until 5.0 m$^{'1}$. We used the systematic method for the value of mixed water substances concentration, with log scale of chlorophyll concentrations.

b. Determination of Apparent Optical Properties

The apparent optical properties of mixed water substances in radiance unit have computed with simple radiative transfer in sea water as below.

Normalized of water leaving radiance is defined as:

$$[L_w(\lambda)]_N = F_0(\lambda)\frac{[\rho_w(\lambda)]_N}{\pi} \qquad (1)$$

where, Fo is extra terrestrial solar irradiance (Thuillier *et al.*, 2002). The relationship between normalized of water leaving reflectance and remote sensing reflectance is:

$$[\rho_w(\lambda)]_N = \pi(t/n)^2 R_{rs}(\lambda) \qquad (2)$$

where, t is transmittances of upward radiance and downward irradiance across the sea surface. n is refractive index of salt water $(t/n)^2$ value is 0.544 (Austin, 1974). R_{rs} is related reflectance (R) that is ratio of upward and downward irradiance (Lee, *et al.*, 1994).

$$R_{rs}(\lambda) = 0.533R(\lambda)/Q \qquad (3)$$

Q is irradiance radiance ratio. Q = 4.5 and R(λ) can be expressed as (Joseph, 1950)

$$R(\lambda) = \frac{k(\lambda) - a(\lambda)}{k(\lambda) + a(\lambda)} \qquad (4)$$

where k(λ) is attenuation coefficient, function of total absorption a(λ) and backscattering coefficient $b_b(\lambda)$.

$$k(\lambda) = \sqrt{a(\lambda)[a(\lambda) + 2.0b_b(\lambda)]} \qquad (5)$$

a(λ) is contributed by water $a_w(\lambda)$ (Pope and Fry, 1997), chlorophyll-a $a_c(\lambda)$ is proportional with concentration and CDOM $a_y(\lambda)$.

$$a(\lambda) = a_w(\lambda) + a_c(\lambda, chl) + a_y(\lambda, a_y(440)) \qquad (6)$$

$a_y(\lambda)$ can be expressed as (Bricaud *et al.*, 1983)

$$a_y(\lambda) = a_y(440)\cdot\exp\{-0.014\cdot(\lambda - 440)\} \qquad (7)$$

$b_b(\lambda)$ is sum of backscattering coefficients:

$$b_b(\lambda) = b_{bw}(\lambda) + b_{bc}(\lambda, chl) + b_{bs}(\lambda, SS) \qquad (8)$$

water b_{bw} (λ) is given by Smith and Beker (1981).

Chlorophyll-a $b_{bc}(\lambda)$ is given by Mobly (1994):

$$b_{bc}(\lambda) = 0.0087\times b_c(\lambda) \qquad (9)$$

$$b_c(\lambda) = 0.27\times chl^{0.698}\left(\frac{550}{\lambda}\right)^{-0.2983} \qquad (10)$$

and suspended matter $b_{bs}(\lambda)$ is given by Fischer and Kronfeld (1986):

$$b_{bs}(\lambda) = b_s(\lambda)\cdot 0.01478 \qquad (11)$$

$$b_s(\lambda) = 0.125\cdot SS\cdot\left(\frac{\lambda}{550}\right)^{-0.812} \qquad (12)$$

c. Data Collection

(1). Sampling Data

Data were collected on May 1-15, September 4-11, and November 13-20 2005 at the Badung Strait at Bali Island and the Saleh Strait at Sumbawa Island (Figure 1.a). The measurements of chlorophyll-a and turbidity concentration are taken around Bali at W115.05 E115.63 N-8.41 S-8.89 (59 points) and Sumbawa Island is at W115.05 E115.63 N-8.0 S-8.89 (152 points). Equipments for the water quality check are WQC-22A/24 TOA-DK and Compact-CTD ACTD 650/687 Alec electronic (Figure 1).

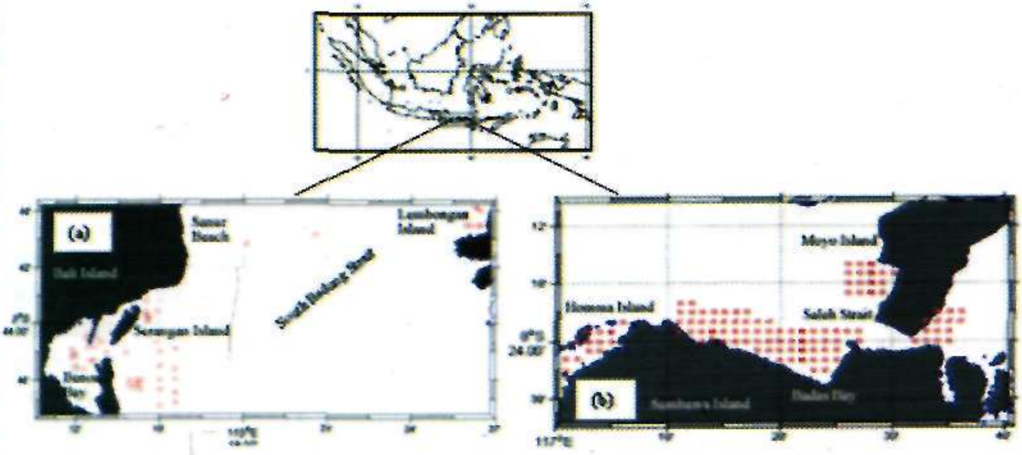

Fig. 1 Stations of Sampling Data (a) Bali (b) Sumbawa

Fig. 2. (a) Water quality check WQC-24 TOA-DK and (b) Compact-CTD ACTD 687 Alec electronic

(2). Satellite Data

MODIS (Moderate Resolution Imaging Spectrometer) data with radiometric calibrated and geolocated radiances L1B 1km swath data are used for the application. The date of acquisitions is synchronous with the date of field observation. Satellite data are processed to level-2 products by the SeaDas software. An atmosphere correction was done by using the iterative method Multi-scattering with 765/865 nm and NIR 10 time iteration. The products are normalized the water leaving radiance at 412, 443, 488, 531, 551, 667, 748, 869 nm.

III. Results and Discusion

Pure sea water has a spectral characteristic in the absorbing light, low at blue band and high at red band. In the scattering light, the spectral characteristic has high at blue band and low at red band. The absorption (a_w) and scattering (b_w) coefficients in m'" of the pure sea water at wave lengths from 340 to 390 nm is observed by Sogandares and Fry (1997), and the values at wave lengths from 400 to 715 nm are measured by Pope and Fry (1997), and from 720 to 750 nm are computed from the complex refractive index measurements by Kou *et al.* (1993). The alternative values of a_w are denoted by Buitveld *et al.* (1994) and Morel (1974). The linear temperature dependence of pure water absorption of ($a_w$dt) is measured by Pegau and Zaneveld (1993) and Pegau *et al.* (1997). See Appendix-1.

The solar spectral irradiance (Fo) from 200 to 2400 nm as measured by the SOLSPEC spectrometer from the ATLAS 1-2-3 and EURECA missions from Thuillier *et al.* (2002). The value of Fo in visible bands is steady in 150 to 200 (mW.cm"^{2}.um"'), except at band 430 nm, Fo become descending. The normalized radiance water leaving of pure sea water NLw *(k)* is computed by equation, NLw *(k)* = JtT2.R(A.) / n2Q. NLw (\)of pure sea water deceases exponentially toward longer wave length, which the maximum value is 3.401 in unit (mW.cm" . um" .sr") at 412 nm and the minimum value is 0.00228 at 700 nm wave length. For the case of absorption spectral of phytoplankton, it is almost by chlorophyll-a, because chlorophyll-b and chlorophyll-c are generally much smaller than chlorophyll-a, which can separate from another substance (suspended matter 0 mg/1 and CDOM absorption 0 m"^{1}). It shows that phytoplankton has more complicated wave length dependence. The examination of the curve shows that it has two major absorption peaks. For the blue band, the maximum is near 440 nm (for the higher concentration is 50 *\ig/* absorption is 2.015 m~'), and for the red band, the maximum is 665 nm (for the higher concentration is 50 ug/1 absorption is 0.945 m"^{1}). In most cases, the blue peak is about three times greater than the red peak (Figure 3).

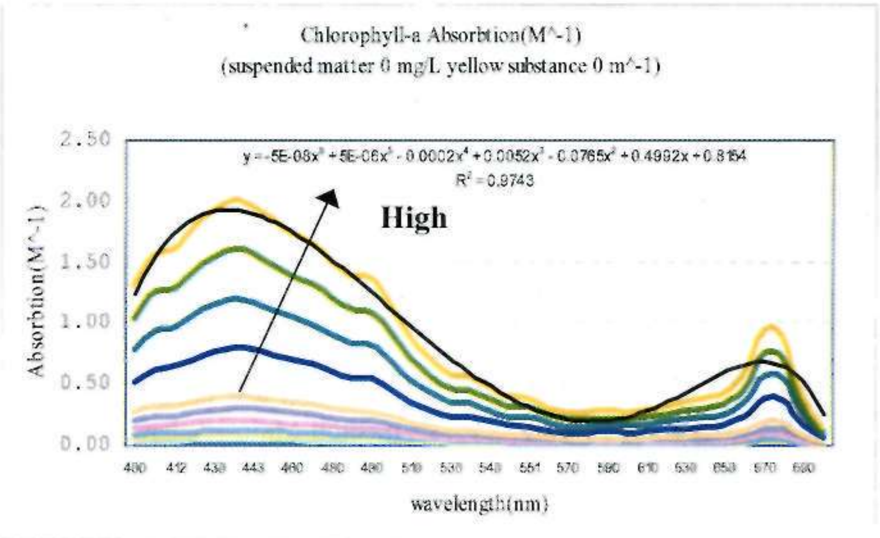

Fig. 3. Peak of Absorption Characteristic of Chlorophyll-a

The chlorophyll-a spectral radiance has a complicated wave length and concentration. Figure 4. illustrates that, the radiance exhibits the following behavior. Firstly, for wave lengths less than 520 nm, the radiance decreases as the concentration increases. At the 400 nm wave length, for the maximum concentration of 50 u.g/1, the radiance is 0.159 in unit, and for the minimum at 0,01 pg/1, the radiance is 2.584 per unit. While at 520 nm, the radiance is approximately independent of concentration, around 0.2745 per unit. The specific case occurs at 430 nm wave length, where radiance also depends on solar irradiance (Fo). At this wave length, Fo suddenly becomes low. Secondly, for the wave length more than 520 nm, the radiance is as increasing as the concentration of chlorophyll until wave length at 680 nm, and then the radiance emitted at 683 nm or in fluorescence peak. Based on this behavior, there are two ways to retrieve the phytoplankton properties (Figure 4).

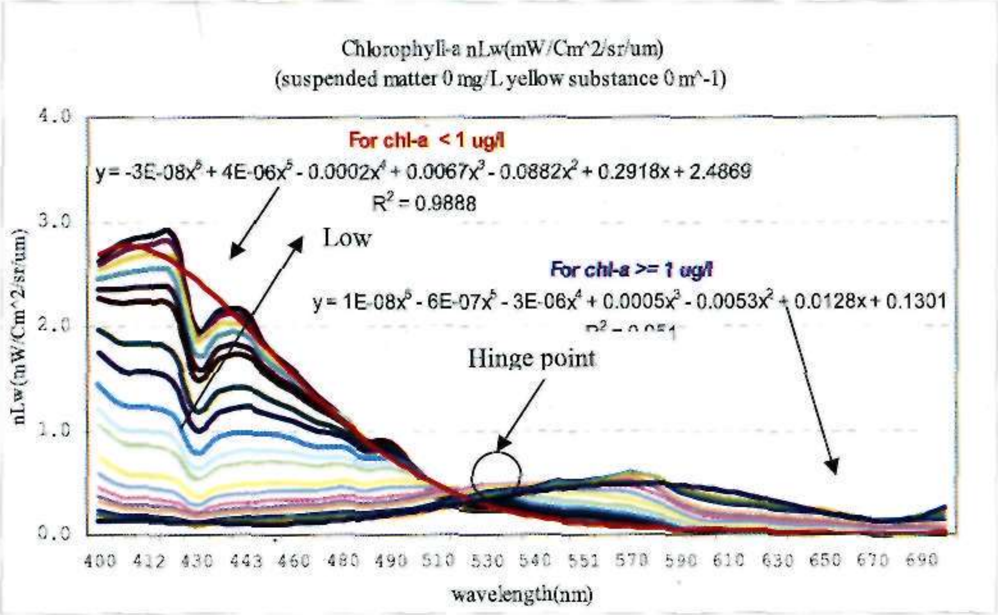

Fig. 4. Characteristic NLw of Chlorophyll-a

Many algorithms make use the reflectance behavior for the wave lengths less than 550 nm. At 443 nm, the radiance peak occurs and in absorption spectral (Figure 3), shows peak at 443 nm. As increasing concentration, the radiance at 443 nm decreases dramatically and the maximum radiance shifts toward 550 nm. Therefore, the increasing concentration and the water leaving radiance become greener. Nevertheless, backscattering energy from water with low chlorophyll-a concentration, more amount contaminated are added to water mass. Non organic suspended matters generally come from the result of rock and soils decay like, silt, clay, mud, sand and dust come from the land brought by the wind. A lot of found in coastal zone become river estuary. As the sediment concentration increasing, the spectral properties of water mass change (see Appendix-2). In term of increasing sediment concentration more than 10 mg/l (Figure 5.) with chlorophyll concentration less than 1 μg/l, the spectral properties of water mass change to the backscattering characteristic of sediment, defined as:

$$b_s(\lambda) = 0.125 \cdot SS \cdot \left(\frac{\lambda}{550}\right)^{-0.812}$$

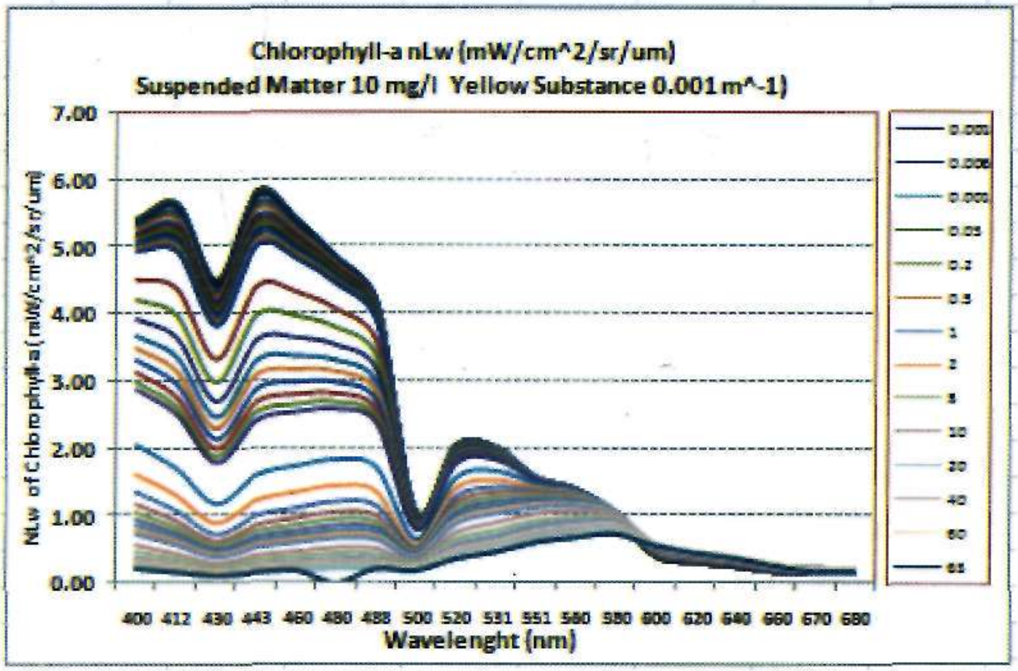

Fig. 5. Characteristic NLw of Chlorophyll-a with 10 mg/l of Sediment

The colored dissolved organic matter (CDOM), which generally comes from the result of rotten plant and animal dissolved and sunk is derived from both terrestrial and oceanic source. Terrestrial CDOM consists of the dissolved humid and fulvic acid, which are primarily derived from the land-based runoff containing vegetable matter. In the open ocean, CDOM is produced when the phytoplankton is degraded by grazing or photolysis. CDOM has strong absorption spectral at 400 nm wave length or in blue band, yielding a brownish yellow color to the water. For each concentration curve of CDOM, the absorption is greatest in the blue band, meanwhile the decrease is exponentially to longer wave lengths (Figure 6). At wave length (A.) for 400 nm < *X* < 700 nm, CDOM absorption can be expressed as follows:

acdom = Acdom(400).exp {-q *(k* -400)}.

where Acdom(400) is the concentration-dependent reference absorption, and q is a specific constant.

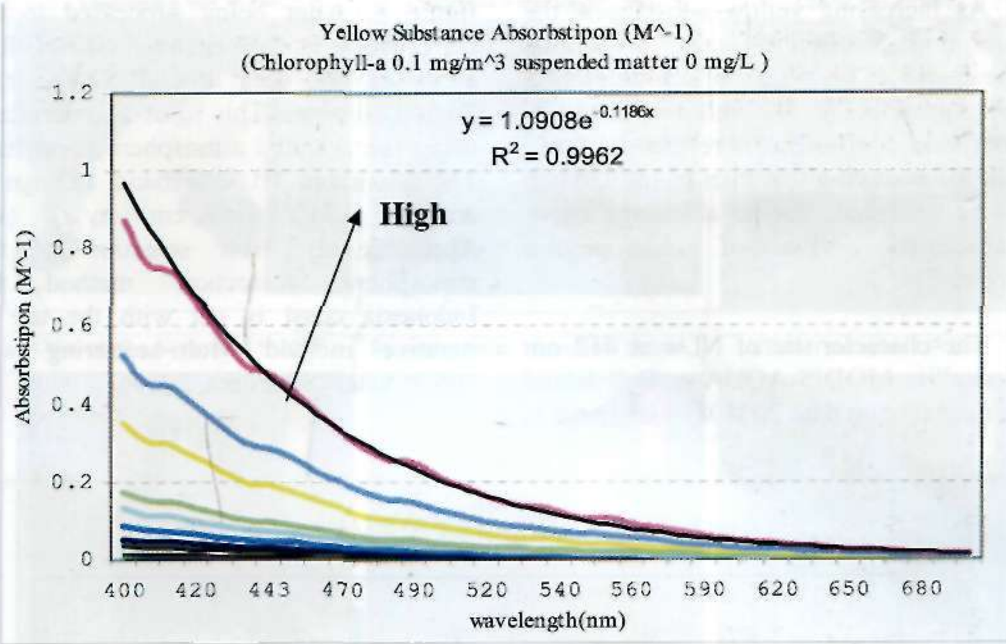

Fig. 6. Absorption Characteristic of CDOM

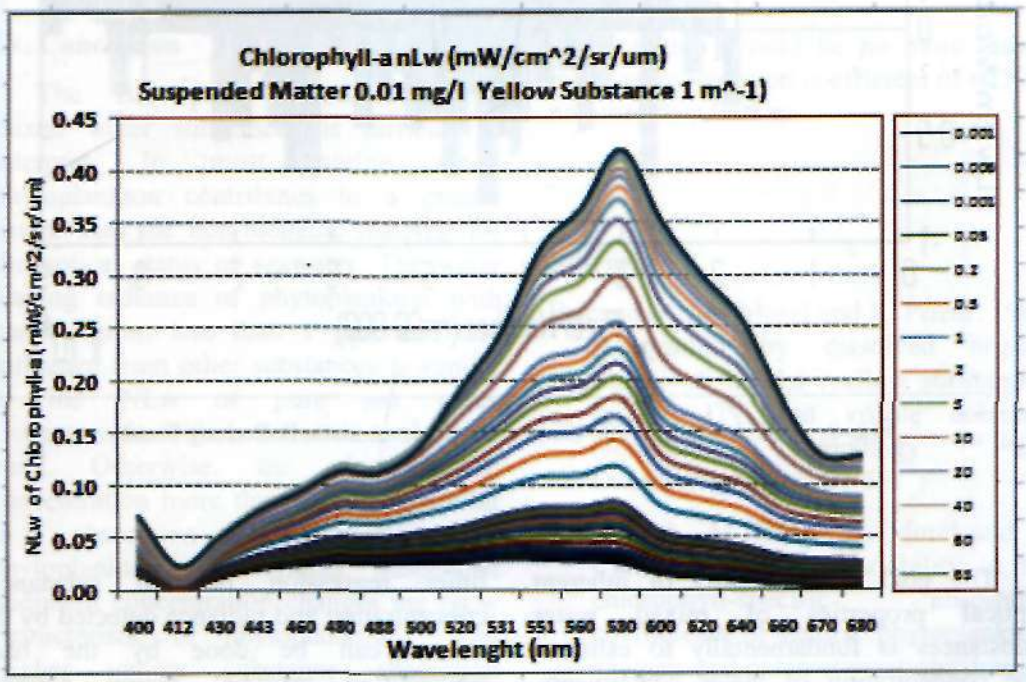

Fig. 7. Characteristic NLw of Chlorophyll-a with 1.0 m^{-1} of CDOM

As increasing yellow substances, the absorption coefficients cause a strange characteristic of NLw of chlorophyll-a (see Appendix-3). The yellow substances absorption coefficient more than 0.01 m"1 with chlorophyll-a less than 15 mg/1, it can not be analyzed, due to a strange curve characteristic NLw of chlorophyll-a (Figure 7).

The characteristic of NLw at 412 ran of satellite MODIS-AQUA at Bali Island area acquisition date 20040819 is shown at figure 8. After being processed to the Level products, the negative value of NLw exists at this area around 5.83% from 90.000 all pixel. This must be minimized using the selected atmosphere correction. The maximum NLw at band 551 nm is around 3.315 (m\V7cm^2/um/sr) (see Appendix 4). Best selection of the atmosphere correction method for Indonesia coast is get with the use of iterative method Multi-scattering with 765/865 nm (Swardika, 2006).

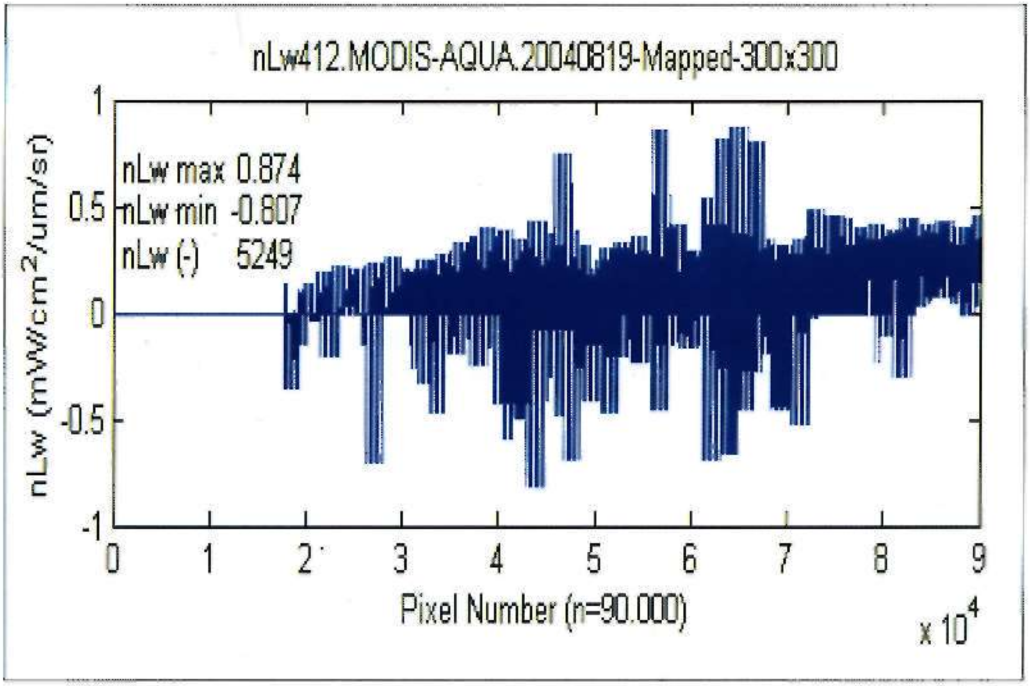

Fig. 8. AQUA MODIS 20040819 NLw Characteristic at Badung Strait

The goal of this study of inherent optical properties of mixed water substances is fundamentally to estimate the concentration of water constituents. From many selected bands of sensor, we can estimate the concentration of three kinds of substances. The complex non-linier regression between substances concentration and radiance detected by the sensor can be done by the back propagation artificial neural network (ANN). Result of MODIS satellite data processing shown at Figure 9.

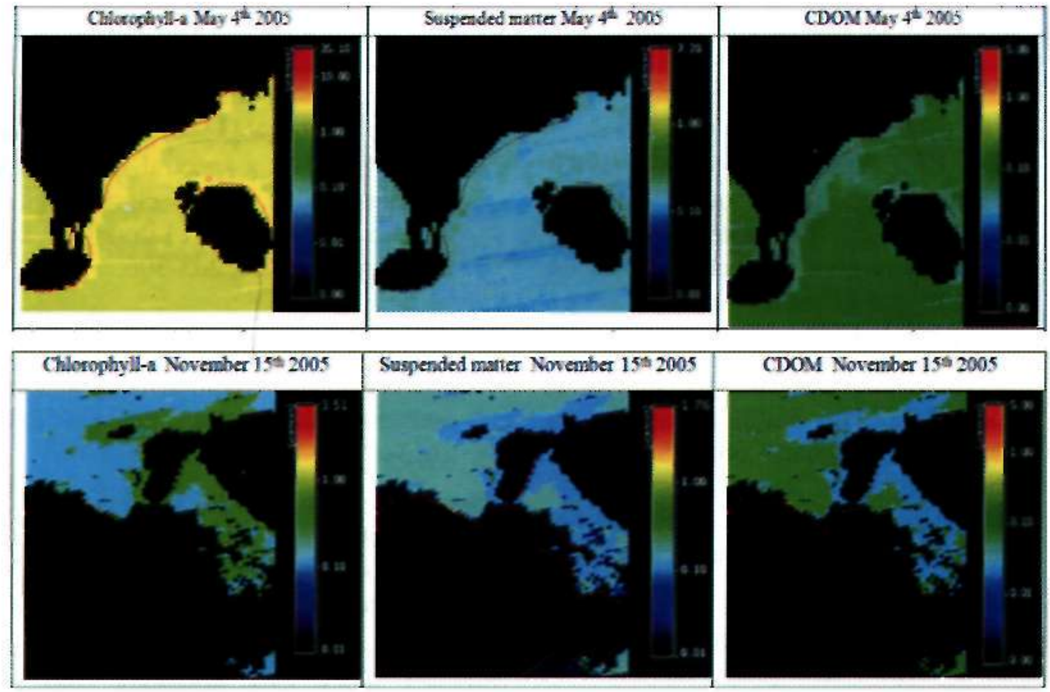

Figure 9. Estimate of water substances concentration by ANN at Badung strait and Sumbawa

IV. Conclusion

The Bio-Optical characteristic of mixed water substances is difficult to interpret. In most marine areas, phytoplankton contributes to a greater extent than the non-biogenic material for the optical status of seawater. The water leaving radiance of phytoplankton with concentration less than 1 ug/1 and less influence from other substances is similar to the **NLw** of pure sea water characteristic. This is reflected at the blue band. Otherwise, the phytoplankton concentration more than 1 ug/1, is similar to absorption characteristic of phytoplankton. The Higher Suspended Sediment concentration changes the NLw characteristic of phytoplankton. The Higher yellow substance absorption coefficients cause the behaviour of the NLw characteristic of phytoplankton strange. To keep the NLw phytoplankton characteristic, **the** Suspended Sediment concentration should be no more than 1 mg/1, and absorption coefficient of CDOM no more than 0.01 m"'.

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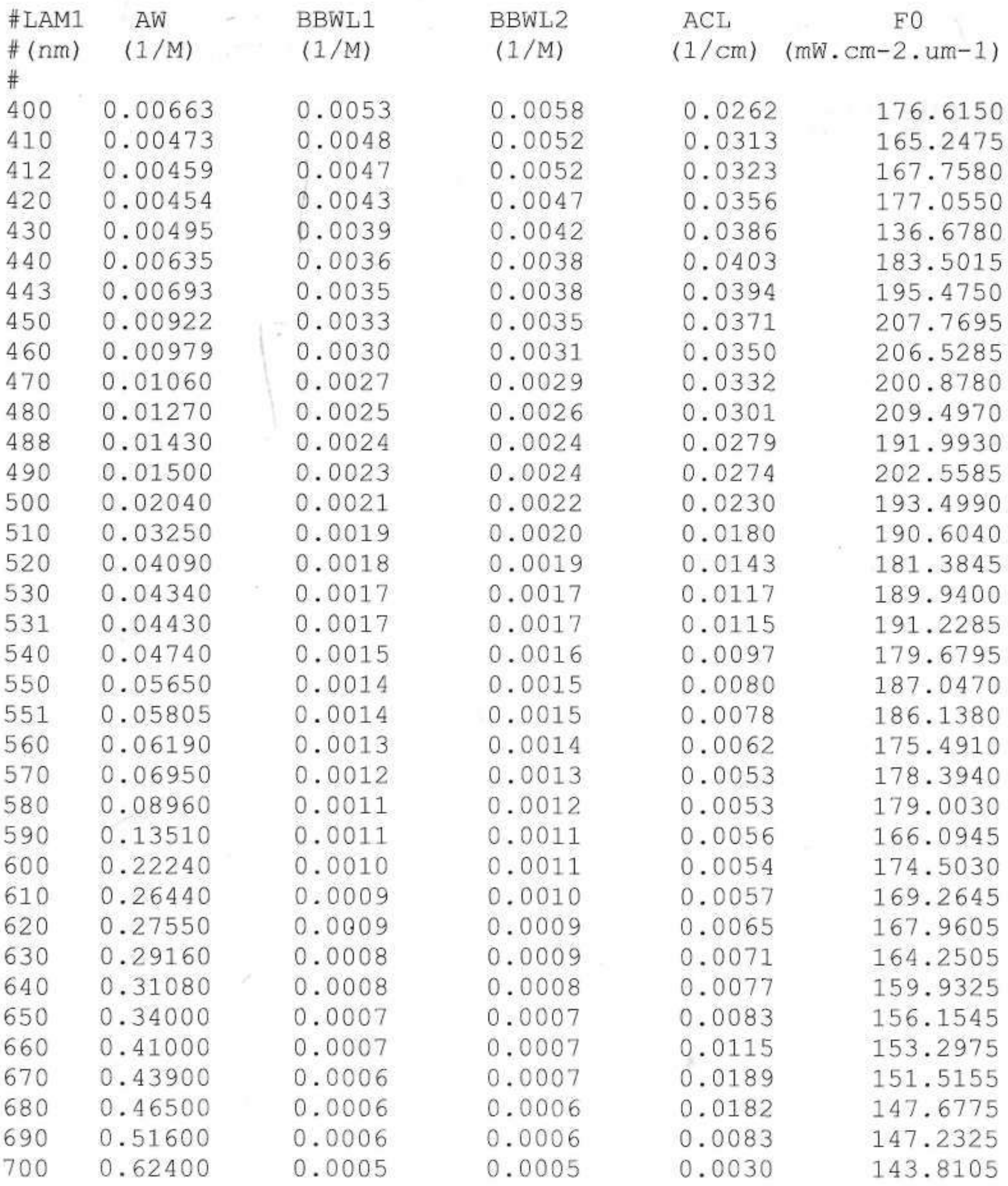
Appendix

APPENDIX-1



#LAM1	AW	BBWL1	BBWL2	ACL	F0
#(nm)	(1/M)	(1/M)	(1/M)	(1/cm)	(mW.cm-2.um-1)
#					
400	0.00663	0.0053	0.0058	0.0262	176.6150
410	0.00473	0.0048	0.0052	0.0313	165.2475
412	0.00459	0.0047	0.0052	0.0323	167.7580
420	0.00454	0.0043	0.0047	0.0356	177.0550
430	0.00495	0.0039	0.0042	0.0386	136.6780
440	0.00635	0.0036	0.0038	0.0403	183.5015
443	0.00693	0.0035	0.0038	0.0394	195.4750
450	0.00922	0.0033	0.0035	0.0371	207.7695
460	0.00979	0.0030	0.0031	0.0350	206.5285
470	0.01060	0.0027	0.0029	0.0332	200.8780
480	0.01270	0.0025	0.0026	0.0301	209.4970
488	0.01430	0.0024	0.0024	0.0279	191.9930
490	0.01500	0.0023	0.0024	0.0274	202.5585
500	0.02040	0.0021	0.0022	0.0230	193.4990
510	0.03250	0.0019	0.0020	0.0180	190.6040
520	0.04090	0.0018	0.0019	0.0143	181.3845
530	0.04340	0.0017	0.0017	0.0117	189.9400
531	0.04430	0.0017	0.0017	0.0115	191.2285
540	0.04740	0.0015	0.0016	0.0097	179.6795
550	0.05650	0.0014	0.0015	0.0080	187.0470
551	0.05805	0.0014	0.0015	0.0078	186.1380
560	0.06190	0.0013	0.0014	0.0062	175.4910
570	0.06950	0.0012	0.0013	0.0053	178.3940
580	0.08960	0.0011	0.0012	0.0053	179.0030
590	0.13510	0.0011	0.0011	0.0056	166.0945
600	0.22240	0.0010	0.0011	0.0054	174.5030
610	0.26440	0.0009	0.0010	0.0057	169.2645
620	0.27550	0.0009	0.0009	0.0065	167.9605
630	0.29160	0.0008	0.0009	0.0071	164.2505
640	0.31080	0.0008	0.0008	0.0077	159.9325
650	0.34000	0.0007	0.0007	0.0083	156.1545
660	0.41000	0.0007	0.0007	0.0115	153.2975
670	0.43900	0.0006	0.0007	0.0189	151.5155
680	0.46500	0.0006	0.0006	0.0182	147.6775
690	0.51600	0.0006	0.0006	0.0083	147.2325
700	0.62400	0.0005	0.0005	0.0030	143.8105

APPENDIX-2

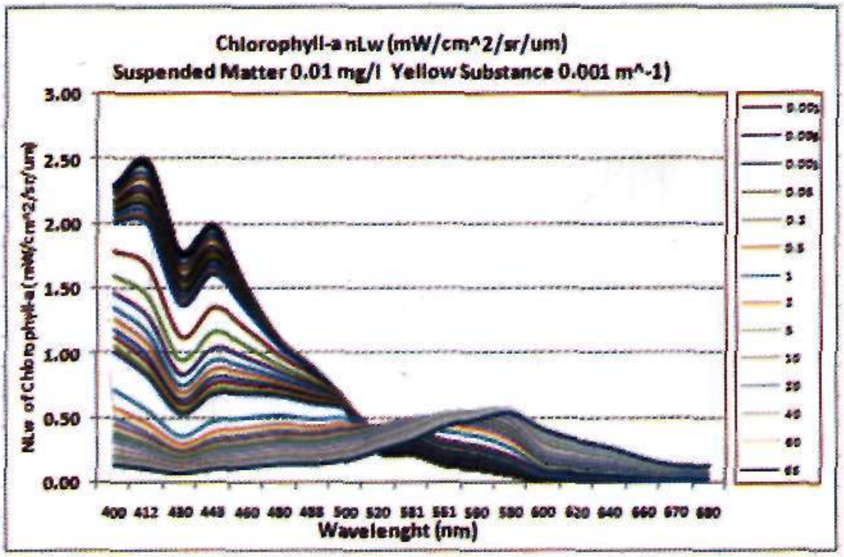


Figure A. Characteristic NLw of Chlorophyll-a with 0.01 mg/l of Sediment

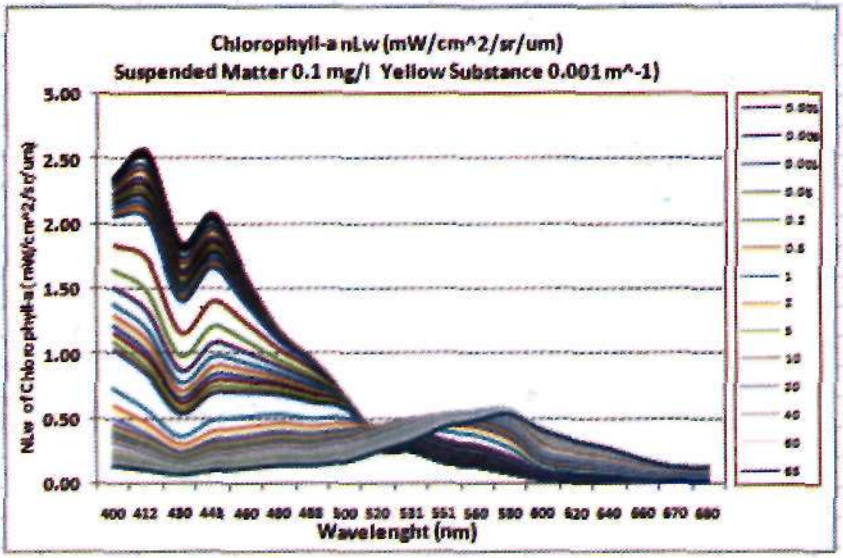


Figure B. Characteristic NLw of Chlorophyll-a with 0.1 mg/l of Sediment

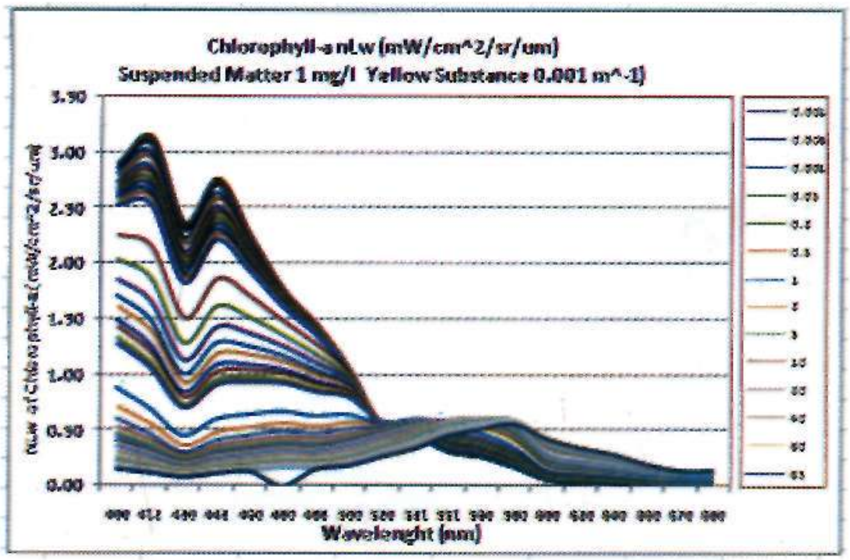


Figure C. Characteristic NLw of Chlorophyll-a with 1.0 mg/l of Sediment

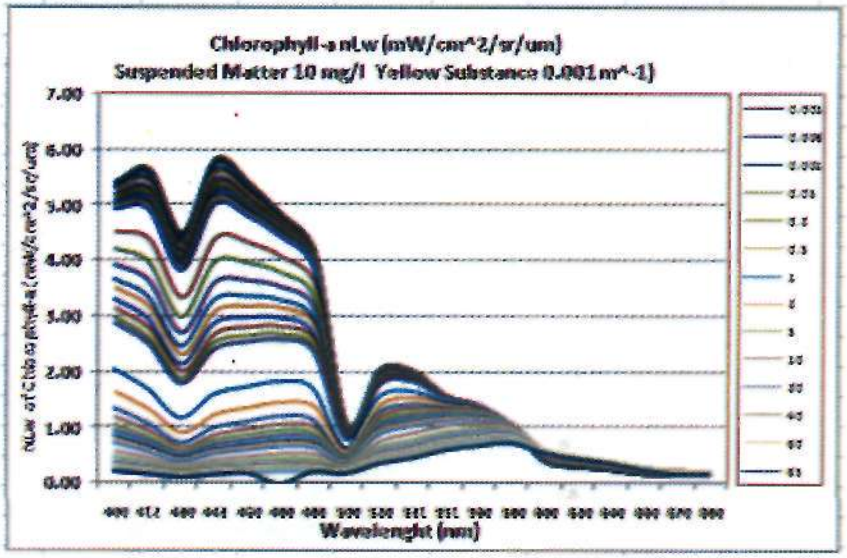


Figure D. Characteristic NLw of Chlorophyll-a with 10.0 mg/l of Sediment

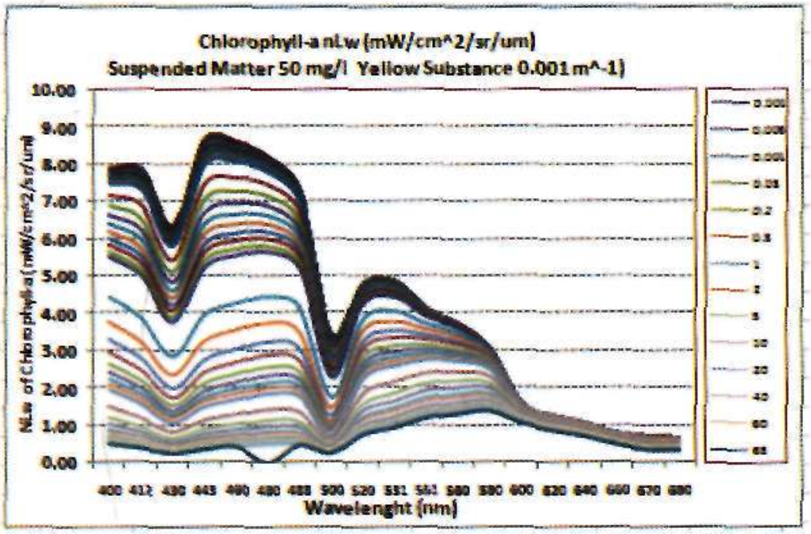


Figure E. Characteristic NLw of Chlorophyll-a with 50.0 mg/l of Sediment

APPENDIX-3

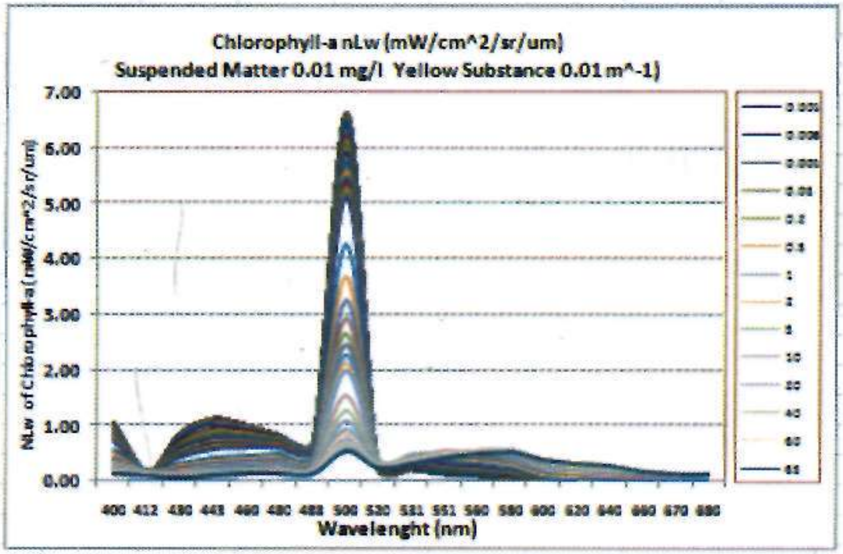


Figure F. Characteristic NLw of Chlorophyll-a with 0.01 m^{-1} of CDOM

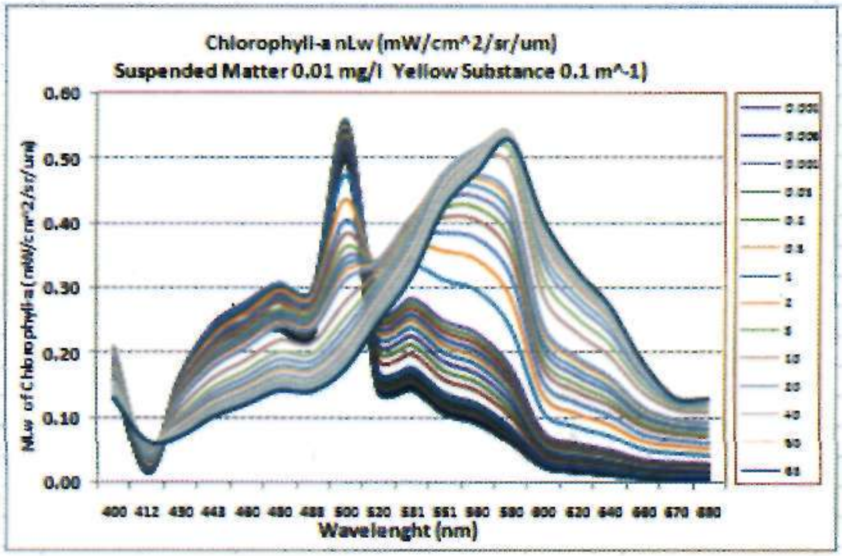


Figure F. Characteristic NLw of Chlorophyll-a with 0.1 m^{-1} of CDOM

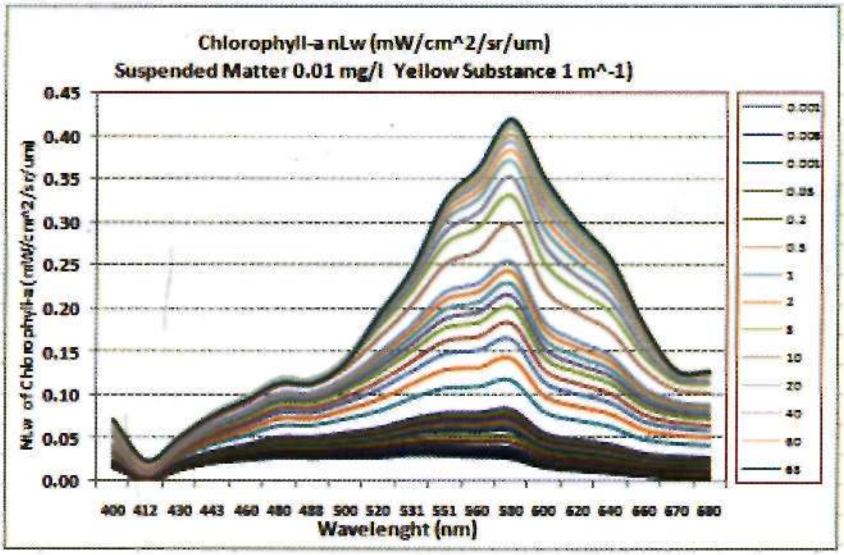


Figure F. Characteristic NLw of Chlorophyll-a with 1.0 m^{-1} of CDOM

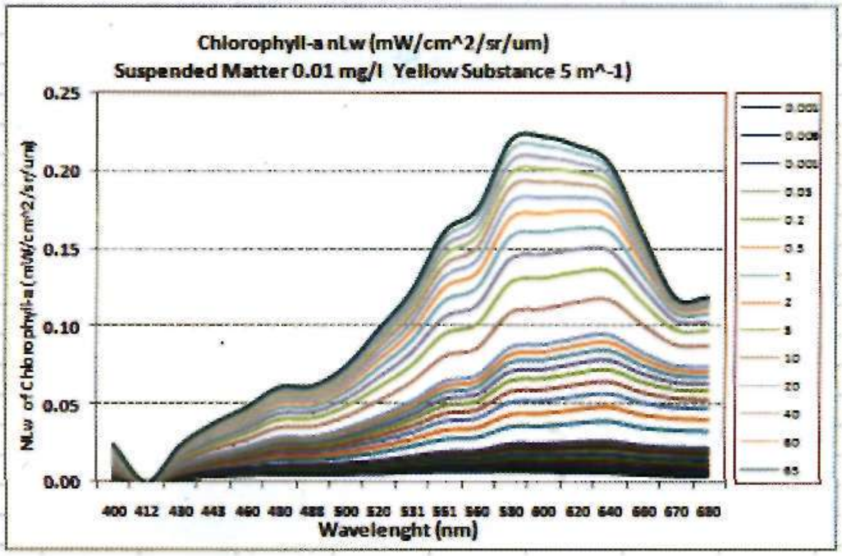
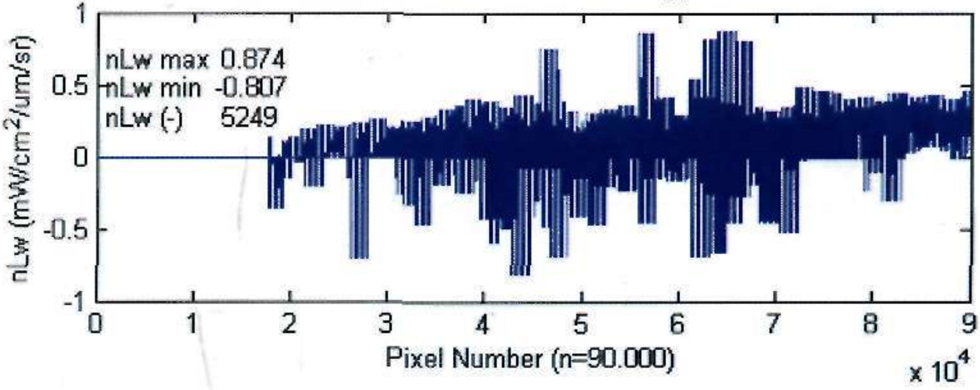
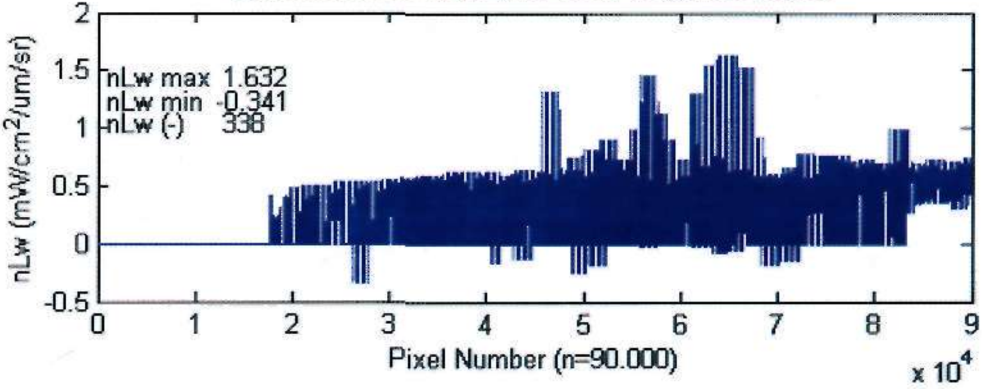


Figure F. Characteristic NLw of Chlorophyll-a with 5.0 m^{-1} of CDOM

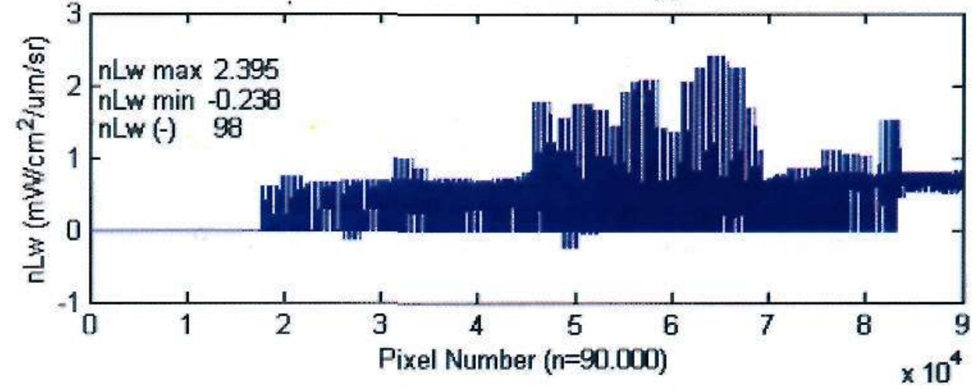
APPENDIX-4



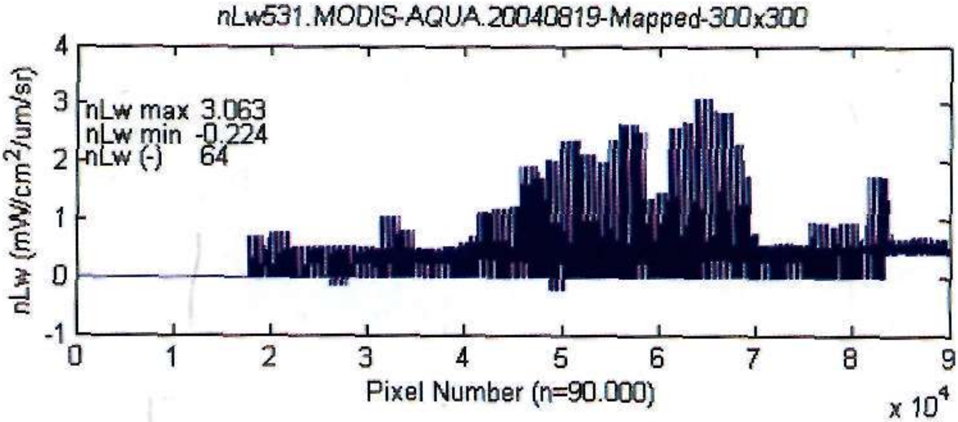
nLw412.MODIS-AQUA.20040819-Mapped-300x300

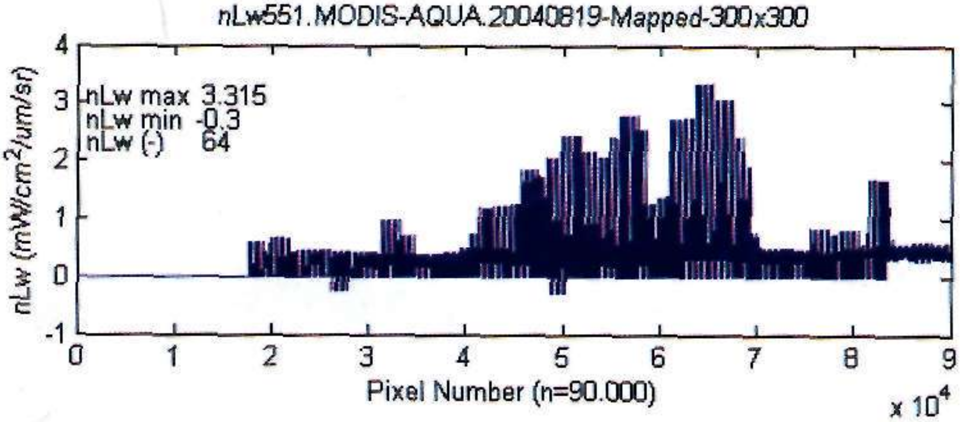


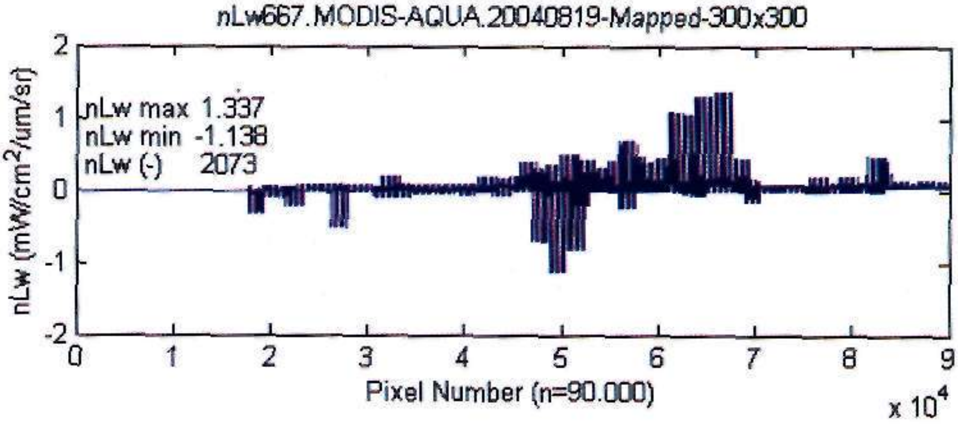
nLw443.MODIS-AQUA.20040819-Mapped-300x300

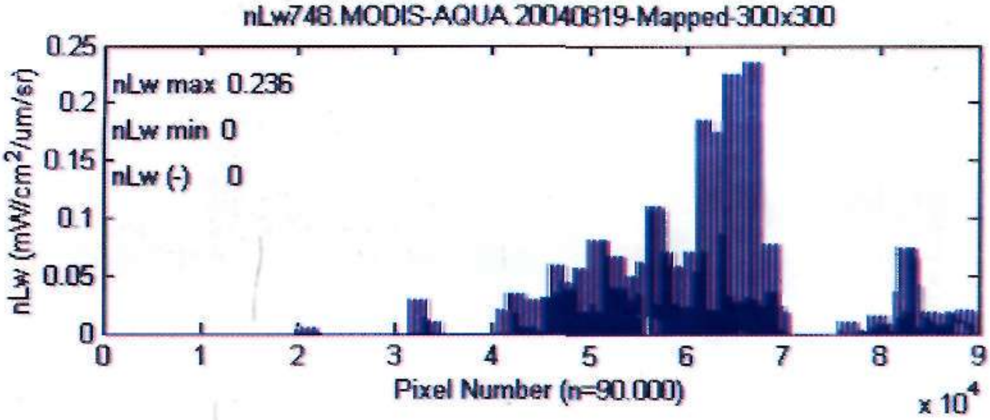


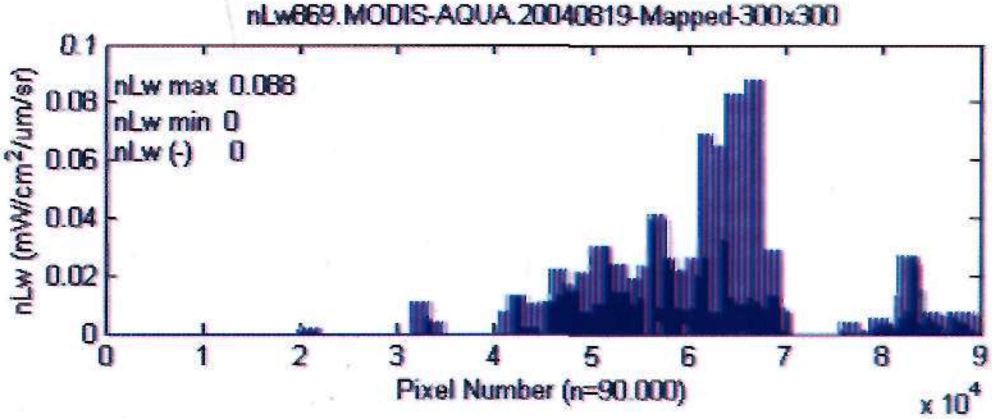
nLw488.MODIS-AQUA.20040819-Mapped-300x300


nLw531.MODIS-AQUA.20040819-Mapped-300x300
nLw (mW/cm^2/um/sr)
nLw max 3.063
nLw min -0.224
nLw (-) 64
4
3
2
1
0
-1
0
1
2
3
4
5
6
7
8
9
Pixel Number (n=90.000)
x 10^4


nLw551.MODIS-AQUA.20040819-Mapped-300x300
nLw (mW/cm^2/um/sr)
nLw max 3.315
nLw min -0.3
nLw (-) 64
4
3
2
1
0
-1
0
1
2
3
4
5
6
7
8
9
Pixel Number (n=90.000)
x 10^4


nLw667.MODIS-AQUA.20040819-Mapped-300x300
nLw (mW/cm^2/um/sr)
nLw max 1.337
nLw min -1.138
nLw (-) 2073
2
1
0
-1
-2
0
1
2
3
4
5
6
7
8
9
Pixel Number (n=90.000)
x 10^4


nLw748.MODIS-AQUA.20040819-Mapped-300x300
nLw max 0.236
nLw min 0
nLw (-) 0
nLw (mW/cm^2/um/sr)
0.25
0.2
0.15
0.1
0.05
0
0
1
2
3
4
5
6
7
8
9
Pixel Number (n=90.000)
x 10^4


nLw869.MODIS-AQUA.20040819-Mapped-300x300
nLw max 0.088
nLw min 0
nLw (-) 0
nLw (mW/cm^2/um/sr)
0.1
0.08
0.06
0.04
0.02
0
0
1
2
3
4
5
6
7
8
9
Pixel Number (n=90.000)
x 10^4